SPECIFICATION

TITLE OF THE INVENTION

Plasma Processing Method and Apparatus Thereof

BACKGROUND OF THE INVENTION

The present invention relates to a plasma processing method and an apparatus thereof for use in manufacturing electron devices and micro machines made of semiconductors and others.

In recent years, thin film processing technique using plasma processing becomes more and more important in the field of manufacturing semiconductor electron devices and micro machines.

As one example of prior art plasma processing methods, plasma processing with use of an inductively coupled plasma source will be described hereinbelow with reference to Fig. 8. In Fig. 8, a specified gas is introduced from a gas supply device 2 into a vacuum chamber 1 while being exhausted therefrom by a pump 3 serving as an exhauster to keep the vacuum chamber 1 within specified pressure. Under such a condition, high-frequency power of 13.56 MHz can be supplied by a high-frequency power source for coil 4 to a coil 23 to generate plasmas in the vacuum chamber 1 to perform plasma processing of a substrate 7 mounted on a substrate electrode 6. In addition, there is provided a high-frequency power source for substrate

electrode 8 for supplying high-frequency power to the substrate electrode 6, which enables control of ion energy reached the substrate 7. It is noted that the coil 23 is disposed on top of a dielectric window 24. The gas is introduced into the vacuum chamber 1 through a plurality of gas supply holes 25 provided on a metal ring 16 which constitutes part of a side wall of the vacuum chamber 1.

However, in order to improve fine processability and enlarge processing area, flow of gas to be used in processing should be increased and processing should be performed under lower pressure, which tends to induce abnormal electrical discharge called hollow cathode discharge in gas supply holes 25 in the prior art plasma processing.

Description of the hollow cathode discharge is as follows. In General, the surface of a solid in contact with plasmas is negatively electrified due to difference in thermal velocity between an electron and an ion, so that the solid surface obtains direct electric fields which send away electrons from the solid surface. In a space surrounded with the solid surface, like the inside of the gas supply hole 25 shown in the prior art, tendency to collision of electrons with the solid surface is reduced due to the presence of the direct electric fields, which prolongs a lifetime of the electrons, resulting in

generation of high-density plasmas (for example, at 100 MHz) inside the gas supply hole 25. Thus-generated electric discharge is called hollow cathode discharge.

The hollow cathode discharge generated in the gas supply hole 25 causes deterioration of the gas supply hole (the lapse of time causes gradual increase of the diameter of the hole) 25 and contamination of a substrate by metal substances constituting the gas supply hole 25.

It is empirically indicated that larger gas velocity in the gas supply hole 25 and larger pressure gradient in the vicinity of the gas supply hole 25 tend to induce hollow cathode discharge. In addition, larger gas flow rate and lower pressure in the vacuum chamber 1 also tends to induce hollow cathode discharge. Accordingly, improvement of fine processability and implementation of larger processing area require larger flow rate of gas for use in processing and processing under lower pressure, which clarifies importance of solving the issue of hollow cathode discharge in the gas supply hole 25.

SUMMARY OF THE INVENTION

In view of the conventional issue stated above, an object of the present invention is to provide a plasma processing method and an apparatus thereof which decreases induction of hollow cathode discharge in the gas supply

hole.

In accomplishing these and other aspects, according to a first aspect of the present invention, there is provided a plasma processing method comprising:

introducing a gas into a vacuum chamber through a hole of a dielectric tube attached to a metal body fixed to the vacuum chamber while exhausting from the vacuum chamber to keep the vacuum chamber within a specified pressure; and

applying high-frequency power with a frequency ranging from 100kHz to 3GHz to a plasma source provided so as to face a substrate mounted on a substrate electrode in the vacuum chamber to generate plasmas in the vacuum chamber to perform plasma processing of the substrate.

According to a aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein the high-frequency power with a frequency ranging from 100kHz to 3GHz is applied to an antenna serving as the plasma source with a dielectric plate interposed between the antenna and the vacuum chamber and with the antenna and the dielectric plate protruded in the vacuum chamber.

According to a second aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein the high-frequency power is applied to an antenna serving as the plasma source

through a penetrating hole given near a center of the dielectric plate with the antenna and the vacuum chamber short-circuited with short pins through penetrating holes which are given at an area located not in a center nor a vicinity of the dielectric plate and which are disposed at approximately equal intervals around a center of the antenna.

According to a third aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein a substrate is processed in a state that a plasma distribution on the substrate is controlled by a circular and groove shaped plasma trap provided between the antenna and the vacuum chamber.

According to a fourth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein a substrate is processed in a state that a plasma distribution on the substrate is controlled by a groove shaped plasma trap provided between the antenna and the metal body which is a ring disposed so as to constitute the plasma trap therebetween.

According to a fifth aspect of the present invention, there is provided a plasma processing method comprising:

introducing a gas into a vacuum chamber through a hole of a dielectric tube attached to a facing electrode provided so as to face a substrate electrode in the vacuum chamber while exhausting from the vacuum chamber to keep the vacuum chamber within a specified pressure; and

applying high-frequency power with a frequency ranging from 100kHz to 3GHz to the substrate electrode or the facing electrode to generate plasmas in the vacuum chamber to perform plasma processing of the substrate.

According to a sixth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein gas supply flow rate per hole given to the dielectric tube is 200sccm or less.

According to a seventh aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein gas supply flow rate per hole given to the dielectric tube is 50sccm or less.

According to an eighth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein the gas is a mixed gas mainly composed of an argon gas.

According to a ninth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein pressure in the vacuum chamber is 10Pa or less.

According to a 10th aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein pressure in the vacuum chamber is 1Pa or less.

According to an 11th aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein a frequency of the high-frequency power applied to the plasma source, the substrate electrode or the facing electrode is 50MHz to 3GHz.

According to a 12th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein gas supply flow rate per hole given to the dielectric tube is 200sccm or less.

According to a 13th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein gas supply flow rate per hole given to the dielectric tube is 50sccm or less.

According to a 14th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein the gas is a mixed gas mainly composed of an argon gas.

According to a 15th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein pressure in the vacuum

chamber is 10Pa or less.

According to a 16th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein pressure in the vacuum chamber is 1Pa or less.

According to a 17th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein a frequency of the high-frequency power applied to the plasma source, the substrate electrode or the facing electrode is 50MHz to 3GHz.

According to an 18th aspect of the present invention, there is provided a plasma processing apparatus comprising:

a vacuum chamber capable of maintaining a vacuum state;

a gas supply device for supplying a gas into the vacuum chamber;

an exhauster for exhausting the gas from the vacuum chamber;

a substrate electrode for mounting a substrate in the vacuum chamber;

a plasma source provided so as to face the substrate electrode;

a high-frequency power source for supplying high-

frequency power with a frequency ranging from 100kHz to 3GHz to the plasma source; and

a dielectric tube having a gas supply hole, attached to a metal body fixed to the vacuum chamber, for passing the gas through the gas supply hole thereof when the gas is supplied to the vacuum chamber by the gas supply device.

According to a 19th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein a dielectric plate is interposed between the vacuum chamber and an antenna serving as the plasma source, and the antenna and the dielectric plate are protruded in the vacuum chamber.

According to a 20th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 19th aspect, wherein high-frequency power is supplied to the antenna through a penetrating hole given near a center of the dielectric plate, and the antenna and the vacuum chamber are short-circuited with short pins through penetrating holes which are given at an area located not in a center nor a vicinity of the dielectric plate and which are disposed at approximately equal intervals around a center of the antenna.

According to a 21st aspect of the present invention, there is provided a plasma processing apparatus

as defined in the 19th aspect, wherein a substrate is processed in a state that a plasma distribution on the substrate is controlled by a circular and groove shaped plasma trap provided between the antenna and the vacuum chamber.

According to a 22nd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the metal body is a ring that constitutes a part of a side wall of the vacuum chamber.

According to a 23rd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 21st aspect, wherein the metal body is a ring disposed so as to constitute a plasma trap between the metal body and the antenna.

According to a 24th aspect of the present invention, there is provided a plasma processing apparatus comprising:

a vacuum chamber capable of maintaining a vacuum state;

a gas supply device for supplying a gas into the vacuum chamber;

an exhauster for exhausting the gas from the vacuum chamber;

a substrate electrode for mounting a substrate in

the vacuum chamber;

a facing electrode provided so as to face the substrate electrode;

a high-frequency power source for supplying high-frequency power with a frequency ranging from 100kHz to 3GHz to the substrate electrode or the facing electrode;

a dielectric tube having a gas supply hole, attached to a metal body fixed to the facing electrode, for passing the gas through the gas supply hole thereof when the gas is supplied to the vacuum chamber by the gas supply device.

According to a 25th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the dielectric tube is a bolt screwed in a tap given to the metal body or the facing electrode.

According to a 26th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the dielectric tube has a spot facing for screwdriver or wrench on a side of an inner wall of the vacuum chamber for rotating and screwing the dielectric tube in the metal plate or the facing electrode.

According to a 27th aspect of the present invention, there is provided a plasma processing apparatus

as defined in the 18th aspect, wherein the dielectric tube is protruded by 0.5 to 20mm from a surface of the metal body or the facing electrode.

According to a 28th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the dielectric tube is protruded by 1 to 10mm from a surface of the metal body or the facing electrode.

According to a 29th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 27th or 28th aspect, wherein the dielectric tube is disposed such that it covers an edge of a hole of the metal body or the facing electrode.

According to a 30th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the hole of the dielectric tube is 0.2 to 2mm in diameter.

According to a 31st aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the hole of the dielectric tube is 0.4 to 0.8mm in diameter.

According to a 32nd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein a frequency of high-frequency power applied to the plasma source, the substrate

electrode or the facing electrode is 50MHz to 3GHz.

According to a 33rd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube is a bolt screwed in a tap given to the metal body or the facing electrode.

According to a 34th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube has a spot facing for screwdriver or wrench on a side of an inner wall of the vacuum chamber for rotating and screwing the dielectric tube in the metal plate or the facing electrode.

According to a 35th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube is protruded by 0.5 to 20mm from a surface of the metal body or the facing electrode.

According to a 36th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube is protruded by 1 to 10mm from a surface of the metal body or the facing electrode.

According to a 37th aspect of the present invention, there is provided a plasma processing apparatus

as defined in the 27th or 28th aspect, wherein the dielectric tube is disposed such that it covers an edge of a hole of the metal body or the facing electrode.

According to a 38th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the hole of the dielectric tube is 0.2 to 2mm in diameter.

According to a 39th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the hole of the dielectric tube is 0.4 to 0.8mm in diameter.

According to a 40th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein a frequency of high-frequency power applied to the plasma source, the substrate electrode or the facing electrode is 50MHz to 3GHz.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, in which:

Fig. 1 is a cross sectional view showing construction of a plasma processing apparatus for use in a

first embodiment of the present invention;

Fig. 2 is a detail view showing the vicinity of a dielectric bush for use in the first embodiment of the present invention;

Fig. 3 is a plane view showing an antenna for use in the first embodiment of the present invention;

Fig. 4 is a cross sectional view showing construction of a case where the present invention is applied to a plasma processing apparatus with a surface wave plasma source;

Fig. 5 is a cross sectional view showing construction of the plasma processing apparatus in a modified example of the first embodiment of the present invention;

Fig. 6 is a cross sectional view showing construction of a plasma processing apparatus for use in a second embodiment of the present invention;

Fig. 7 is a detail view showing the vicinity of a dielectric bush for use in the second embodiment of the present invention;

Fig. 8 is a cross sectional view showing construction of a plasma processing apparatus for use in the prior art;

Fig. 9 is a perspective view of the dielectric bush according to the first embodiment;

Fig. 10 is a sectional view of a dielectric bush according to a first modification of the first embodiment;

Fig. 11 is a sectional view of a dielectric bush according to a second modification of the first embodiment;

Fig. 12 is a sectional view of a dielectric bush according to a third modification of the first embodiment;

Fig. 13 is a perspective view of the dielectric bush according to the third modification of the first embodiment; and

Fig. 14 is a sectional view of a dielectric bush according to a fourth modification of the first embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

Description will now be given of the first embodiment of the present invention with reference to Figs. 1 to 3.

Fig. 1 shows a cross sectional view of a plasma processing apparatus for use in the first embodiment of the present invention. In Fig. 1, a specified gas is introduced from a gas supply device 2 into a vacuum chamber 1 while being exhausted therefrom by a pump 3 serving as an

example of an exhauster to keep the vacuum chamber 1 within a specified pressure. Under such a condition, high-frequency power of 100 MHz can be supplied by a high-frequency power source for antenna 4 to an antenna 5, as one example of a plasma source, protruded into the vacuum chamber 1 to generate plasmas in the vacuum chamber 1 to perform plasma processing of a substrate 7 mounted on a substrate electrode 6. In addition, there is provided a high-frequency power source for substrate electrode 8 for supplying high-frequency power to the substrate electrode 6, which enables control of ion energy reached the substrate 7. High-frequency voltages supplied to the antenna 5 is guided by a feed bar 9 to a central part of the antenna 5. A plurality of areas located not in the center nor the vicinity of the antenna 5 and a plane 1A facing the substrate 7 of the vacuum chamber 1 are short-circuited by short pins 10. A dielectric plate 11 is interposed between the antenna 5 and the vacuum chamber 1. Through penetrating holes provided on the dielectric plate 11, the feed bar 9 and the short pins 10 connect the antenna 5 to the high-frequency power source for antenna 4 and the antenna 5 to a vacuum chamber 1, respectively. The surface of the antenna 5 is covered with an insulative cover 12. There is provided a plasma trap 15 made up of a groove-shaped space between the dielectric plate 11 and a

dielectric ring 13 placed in the vicinity of the dielectric plate 11, and a groove-shaped space between the antenna 5 and a conduction ring 14 placed in the vicinity of the antenna 5. By the gas supply device 2, the gas is introduced into the vacuum chamber 1 through a gas supply hole 18 (See Fig. 2) provided on a dielectric bush 17, as one example of a dielectric tube, attached to a metal ring 16 which constitutes a part of a side wall of the vacuum chamber 1 and has a ring-shaped gas passage 16a therein and is made of metal such as aluminum or stainless steel.

Fig. 2 shows a detail view around the dielectric bush 17 made of ceramic as one example. On the side of the inner wall of the vacuum chamber 1, there is provided a spot facing for screw driver 19 (See Fig. 9) for rotating and screwing the dielectric bush 17 in the metal ring 16. The metal ring 16 is equipped with a tap 20 for screwing in the dielectric bush 17. The dielectric bush 17 has the shape of a bolt. The dielectric bush 17 is protruded by 5mm from the surface of the metal ring 16. The dielectric bush 17 is disposed such that it covers an edge 21 of a hole provided on the metal ring 16. A gas supply hole 18 given on the dielectric bush 17 is 0.5mm in diameter. The metal ring 16 is equipped with total 8 dielectric bushes 17, making it possible to blow out gas into the vacuum chamber 1 in approximately isotropic direction. Fig. 3 shows a

plane view of the antenna 5. In Fig. 3, the short pins 10 are put in three locations. Each of three short pins 10 is disposed at equal intervals around the center of the antenna 5.

With the plasma processing apparatus shown in Figs. 1 to 3, a substrate having an iridium film was etched. Etching was conducted under the conditions of argon gas of 260sccm and chlorine gas of 20sccm, pressure of 0.3Pa, antenna power of 1500W, and substrate electrode power of 400W. Total gas flow rate was 260+20 = 280sccm, and the number of gas supply holes was 8, so that gas supply flow rate per gas supply hole was 280/8 = 35sccm. As a result of etching under such conditions, hollow cathode discharge in each gas supply hole 18 did not occur, and therefore good discharge condition was obtained.

The reason why the hollow cathode discharge could be suppressed may be that high-frequency electric fields in each gas supply hole 18 were weakened compared to those in the prior art example. It can be considered that an inclination to occurrence of the hollow cathode discharge is largely influenced by high-frequency electric fields reached the gas supply holes as well as gas velocity or pressure gradient. It can be considered that composing the vicinity of each gas supply hole 18 of a dielectric substance and protruding the dielectric bush 17 by 5mm from

the surface of the metal ring 16 weaken high-frequency electric fields in an outlet of each gas supply hole 18, thereby enabling suppression of the hollow cathode discharge.

The above-described first embodiment of the present invention is just one example of a number of variations available in the shape of the vacuum chamber as well as the shape and disposition of the antenna within an applicable range of the present invention. It will be understood that diverse variations other than the one exemplified here above are available in application of the present invention.

In the above described first embodiment of the present invention, high-frequency voltage is supplied to the antenna through a penetrating hole given near the center of the dielectric plate, and the antenna and the vacuum chamber are short-circuited with the short pins through penetrating holes which are given at an area located not in the center nor the vicinity of the dielectric plate and which are disposed at approximately equal intervals around the center of the antenna. Such construction makes it possible to increase isotropy of plasmas. In the case of handling a small substrate, the present invention ensures sufficiently high inplane uniformity without use of the short pins.

Further, in the first embodiment of the present invention, there has been described the case of processing the substrate in the state that the plasma distribution on to the substrate was controlled by the circular and groove shaped plasma trap provided between the antenna and the vacuum chamber. Such construction contributes to increase uniformity of plasmas. In the case of handling a small substrate, the present invention ensures sufficiently high inplane uniformity without use of the plasma trap.

The present invention is also effective when using as an antenna the coil 23 in the case with the inductively coupled plasma source shown in Fig. 8 describing the prior art example or an electromagnetic radiation antenna 26 in the case with a surface wave plasma source shown in Fig. 4.

Further in the first embodiment of the present invention shown above, the metal body with the dielectric bush embedded is the ring that constitutes a part of the side wall of the vacuum chamber. Such construction is also effective when, as shown in Fig. 5, a metal body with a dielectric bush embedded is a conduction ring 14 disposed so as to constitute a plasma trap between the metal body and the antenna.

Description will now be given of a second embodiment of the present invention with reference to Figs.

6 to 7.

Fig. 6 is a cross sectional view of a plasma processing apparatus for use in the second embodiment of the present invention. In Fig. 6, a specified gas is introduced from a gas supply device 2 into a vacuum chamber 1 while being exhausted therefrom by a pump 3 serving as an example of an exhauster to keep the vacuum chamber 1 within a specified pressure. Under such a condition, high-frequency power of 13.56 MHz can be supplied by a high-frequency power source for substrate electrode 8 to a substrate electrode 6 to generate plasmas in the vacuum chamber 1 to perform plasma processing of a substrate 7 mounted on a substrate electrode 6. There is provided a facing electrode 22 that faces the substrate electrode 6 and has therein a gas passage 22a connected to a plurality of holes with taps 20. The gas is introduced into the vacuum chamber 1 through a gas supply hole 18 (See Fig. 7) given to a dielectric bush 17, as one example of a dielectric tube, placed on the facing electrode 22.

Fig. 7 shows a detail view around the dielectric bush 17 made of ceramic as one example. On the side of the inner wall of the vacuum chamber 1, the dielectric bush 17 has a spot facing for screw driver 19 (See Fig. 9) for rotating and screwing the dielectric bush 17 in the facing electrode 22. The facing electrode 22 is equipped with a

tap 20 for screwing in the dielectric bush 17. The dielectric bush 17 has the shape of a bolt. The dielectric bush 17 is protruded by 5mm from the surface of the facing electrode 22. The dielectric bush 17 is disposed such that it covers an edge 21 of a hole provided on the facing electrode 22. A gas supply hole 18 given on the dielectric bush 17 is 0.5mm in diameter. The facing electrode 22 is equipped with total 80 dielectric bushes 17, making it possible to blow out gas toward a substrate in the vacuum chamber 1.

With the plasma processing apparatus shown in Figs. 6 to 7, a substrate having an aluminum film was etched. Etching was conducted under the conditions of chlorine gas of 200sccm, boron trichloride gas of 600sccm, argon gas 800sccm, pressure of 5Pa, and substrate electrode power of 4kW. Total gas flow rate was 200+600+800 = 1600sccm, and the number of gas supply holes was 80, so that gas supply flow rate per gas supply hole was 1600/80 = 20sccm. As a result of etching under such conditions, hollow cathode discharge in each gas supply hole 18 did not occur, and therefore good discharge condition was obtained.

The reason why the hollow cathode discharge could be suppressed may be that high-frequency electric fields in each gas supply hole 18 were weakened compared to those in the prior art example. It can be considered that an

inclination to occurrence of the hollow cathode discharge is largely influenced by high-frequency electric fields reached the gas supply holes as well as gas velocity or pressure gradient. It can be considered that composing the vicinity of each gas supply hole 18 of a dielectric substance and protruding the dielectric bush 17 by 5mm from the surface of the facing electrode 22 weaken high-frequency electric fields in an outlet of each gas supply hole 18, thereby enabling suppression of the hollow cathode discharge.

In the above described embodiments of the present invention, the dielectric bush is a bolt screwed in the tap given to the metal body or the facing electrode. However, the dielectric bush is not necessarily in the shape of a bolt, but may be embedded to the metal body or the facing electrode in the shape of a wedge. The dielectric bush in the shape of a bolt has an advantage that replacement thereof as an expendable component is easy.

Further, there has been described that the dielectric bush had a spot facing for screw driver on the side of the inner wall of the vacuum chamber for rotating and screwing the dielectric bush in the metal plate or the facing electrode. However, other than the spot facing for screw driver, the present invention may adopt shapes for various tools such as wrenches. It goes without saying

that the spot facing is not necessary if the dielectric bush is wedge-shaped.

As described above, the dielectric bush is protruded by 5mm from the surface of the metal body or the facing electrode. Since an experimental result proves that approx. 0.5mm or more protrusion is desirable, the length of protrusion of the dielectric bush is preferably within this range. However, excessive protrusion may lead to breakage of the dielectric bush, and therefore the dielectric bush may preferably be protruded by approx. 20mm or less. Accordingly, an optimum length of protrusion of the dielectric bush is considered to be about 1 to 10mm, which surely ensures suppression of hollow cathode discharge and prevents breakage of the dielectric bush.

As described above, the dielectric bush is disposed such that it covers the edge of the hole provided on the metal body or the facing electrode. Such construction is preferable since it can effectively prevent the edge of the hole provided on the metal body or the facing electrode from deteriorating due to exposure to plasmas for a long period of time.

As described above, the hole given on the dielectric bush is 0.5mm in diameter. Since an experimental result proves that a smaller hole reduces a tendency to occurrence of hollow cathode discharge, the

size of the hole is preferably about 2mm or less. However too small a hole increases difficulty in processability, and therefore the diameter of the hole is preferably 0.2mm or more. Accordingly, an optimum diameter of the hole is considered to be about 0.4 to 0.8mm, which ensures suppression of hollow cathode discharge and facilitates processing.

There were described the cases where the gas supply flow rate per hole given to the dielectric bush was 35sccm and 20sccm. Since an experimental result proves that smaller gas supply flow rate per hole reduces a tendency to occurrence of hollow cathode discharge, gas supply flow rate per hole is preferably around 200sccm or less. For more secure suppression of hollow cathode discharge, gas supply flow rate per hole given to the dielectric bush is preferably 50sccm or less. To meets such conditions, increase of the number of the gas supply holes is effective as well as decrease of gas flow rate in plasma processing.

As described above, a gas for use in the present invention is a mixed gas mainly composed of an argon gas. It is empirically proved that a tendency to occurrence of hollow cathode discharge differs by types of gases, and an argon gas considerably increases the tendency. Accordingly, the present invention is particularly effective when a

mixed gas mainly composed of an argon gas is in use. In the case of using other gases, the present invention is also quite effective for suppression of hollow cathode discharge.

There were also described the cases where the pressure in the vacuum chamber was 0.3Pa and 5Pa. Since lower pressure in the vacuum chamber increases a tendency to occurrence of hollow cathode discharge, the present invention is effective when the pressure in the vacuum chamber is 10 Pa or less. The present invention is further effective when the pressure in the vacuum chamber is 1Pa or less.

There were described the cases where a frequency of high-frequency power applied to the antenna, the substrate electrode or the facing electrode was 100MHz or 13.56MHz. In plasma processing with low pressure, there can be used high-frequency power ranging from 100kHz to 3GHz, and over such a broad range, the present invention is effective. However, with a higher frequency of high-frequency power, electromagnetic waves tend to spread in a wider range, which tends to increase high-frequency electric fields in the gas supply hole. Accordingly, the present invention is effective when a frequency of high frequency power is high, especially in the range from 50MHz to 3GHz.

Fig. 10 is a sectional view of a dielectric bush 17A according to a first modification of the first embodiment. The dielectric bush 17A has a spot facing 17g at the inner end side thereof with the diameter of the spot facing lager than the diameter of the gas supply hole 18 and with the spot facing 17g connected to the gas passage 16a. The distance of the gas supply hole 18 is not less than 1mm, preferably, so as to surely obtain the above effects.

Fig. 11 is a sectional view of a dielectric bush 17B according to a second modification of the first embodiment where the dielectric bush 17B is not protruded from the surface of the metal ring 16 in a case where Ar gas and the antenna power of 500W or less are used.

Figs. 12 and 13 are a sectional view and a perspective view of a dielectric bush 17C according to a third modification of the first embodiment where the dielectric bush 17C has a projection 17h, instead of a screw portion, for engaging with a recess 16h. The projection 17h can pass through a groove 16j of the metal ring 16 and then the dielectric bush 17C is rotated to engage the projection 17h with the recess 16h, so that the dielectric bush 17C is not taken out from the metal ring 16 in its axial direction. When the dielectric bush 17C is taken out from the metal ring 16, the dielectric bush 17C

is rotated to insert the projection 17h into the groove 16j, so that the dielectric bush 17C is taken out from the metal ring 16 in its axial direction.

Fig. 14 is a sectional view of a dielectric bush 17D according to a fourth modification of the first embodiment where the whole of the dielectric bush 17D is protruded from the surface of the metal ring 16 with the gas supply hole 18 connected to a gas hole 16i of the metal ring 16.

As is clear from the above description, according to the plasma processing method in the present invention, the gas is introduced into the vacuum chamber while being exhausted therefrom to keep the vacuum chamber within a specified pressure. Under such a condition, high-frequency power with a frequency ranging from 100kHz to 3GHz is applied to the plasma source such as the antenna provided so as to face the substrate mounted on the substrate electrode in the vacuum chamber to generate plasmas in the vacuum chamber to perform plasma processing of the substrate. In this method, the gas is supplied to the vacuum chamber through the hole given to the dielectric bush embedded in the metal body, which implements plasma processing that reduces a tendency to occurrence of hollow cathode discharge in the gas supply hole.

According to the plasma processing method in the

present invention, the gas is introduced into the vacuum chamber while being exhausted therefrom to keep the vacuum chamber within a specified pressure. Under such a condition, high-frequency power with a frequency ranging from 100kHz to 3GHz is applied to the substrate electrode or the facing electrode provided so as to face the substrate electrode in the vacuum chamber to generate plasmas in the vacuum chamber to perform plasma processing of a substrate mounted on the substrate electrode. In this method, the gas is supplied to the vacuum chamber through the hole given to the dielectric bush embedded in the facing electrode, which implements plasma processing that reduces a tendency to occurrence of hollow cathode discharge in the gas supply hole.

According to the plasma processing apparatus in the present invention, the plasma processing apparatus is made up of the vacuum chamber, the gas supply device for supplying the gas into the vacuum chamber, the exhauster for exhausting the gas from the vacuum chamber, the substrate electrode for mounting the substrate in the vacuum chamber, the plasma source such as the antenna provided so as to face the substrate electrode, and the high-frequency power source for supplying high-frequency power with a frequency ranging from 100kHz to 3GHz to the antenna. In this device, the gas is supplied to the vacuum

chamber through the hole given to the dielectric bush embedded in the metal body, which implements plasma processing that reduces a tendency to occurrence of hollow cathode discharge in the gas supply hole.

According to the plasma processing apparatus in the present invention, the plasma processing apparatus is made up of the vacuum chamber, the gas supply device for supplying the gas into the vacuum chamber, the exhauster for exhausting the gas from the vacuum chamber, the substrate electrode for mounting the substrate in the vacuum chamber, the facing electrode provided so as to face the substrate electrode, and the high-frequency power source for supplying high-frequency power with a frequency ranging from 100kHz to 3GHz to the substrate electrode or the facing electrode. In this device, the gas is supplied to the vacuum chamber through the hole given to the dielectric bush embedded in the facing electrode, which implements plasma processing that reduces a tendency to occurrence of hollow cathode discharge in the gas supply hole.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and

modifications are to be understood as included within the scope of the present invention as defined by the appended claims unless they depart therefrom.